DESIGN AND PERFORMANCE OF THE PRE-FIRE DETECTION SYSTEM FOR THE FRX-L MAIN CAPACITOR

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Abstract

The Main Capacitor Bank of the FRX-L (Field-Reversed Configuration eXperiment) supplies current (1.6 Meg amp) to a single-turn coil that is used to create high-density plasmas for magnetized-target fusion (MTF) experiments. The energy stored in the main bank (200 kJ) is transferred to the load coil via an array of four Maxwell rail-gap switches in parallel. Each switch is capable of transferring approximately a quarter of the main bank charge flow without damage. Therefore, if a single switch pre-fires it is subject to much greater stress than it is able to tolerate. In this paper, we discuss the design and performance of a system that is able to discriminate between a switch pre-fire, trigger noise, and normal operation and initiate a trigger in time to safely prevent damage. This system consists of innovative electric field detectors, fiber-optic isolation of signals and high-speed solid-state circuitry that interfaces with the Maxwell trigger system without modification.

I. INTRODUCTION

The Field-Reversed Configuration eXperiment-*Liner* work being conducted at Los Alamos National Lab for the Magnetized Target Fusion MTF) program focuses on producing a high density field reversed configuration (FRC) plasma that is injected into an aluminum liner and compressed toward fusion.

An FRC plasma is one in which a gas (usually deuterium) is ionized and formed into an elongated toroid by applying successive magnetic fields. This configuration is stable and can be confined for a short period of time. Because of the lifetime of this plasma, it can be translated from one position to another and further compressed by additional magnetic fields.

The formation, translation and compression of an FRC plasma requires the use of high energy pulsed power systems as shown in Fig. 1. Such systems provide the current drive thru the solenoid to produce the magnetic fields that in turn ionize and form the FRC plasma. These systems are designed to withstand high mechanical and electrical stress for many discharges.

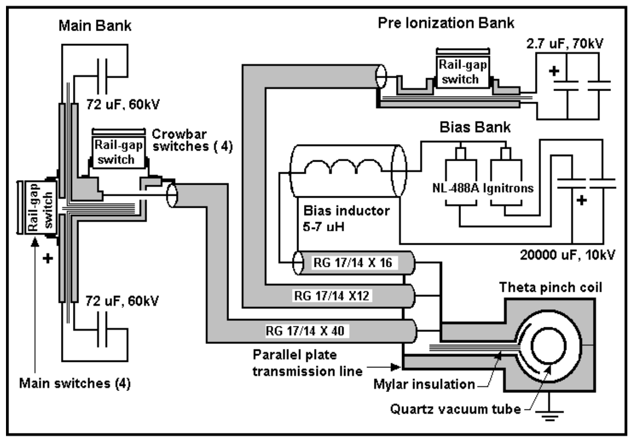

Figure 1. FRX-L Schematic

In this report we present the design and performance details of a Pre-fire Detection System built for the Los Alamos MTF facility to protect the Main Capacitor Bank switches of the FRX-L pulsed power system in the case of a potentially destructive pre-fire fault. FRX-L is a small pulsed power system by comparison to earlier field-reverse experiments such as FRX-C, however the system architecture is essentially the same, consisting of a P.I. (Pre-ionization) Bank, Bias Bank, Main Bank and Crowbar switches, all connected in parallel, to the Theta-pinch coil (a single turn solenoid surrounding a quartz tube under vacuum). The discharge of the capacitor banks must be separate and correctly timed to create FRC plasmas, therefore any single bank cannot be allowed to influence the correct operation of the other banks. There is no isolation between the Main Bank rail-gap switches, as they are mounted side by side in parallel. If a single switch pre-fires during charging of the bank the entire bank will discharge through this switch. This will greatly exceed its rated capacity of 10 Coulombs [2] and destroy the switch.

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II. OPTICALLY ISOLATED DETECTOR

A simple and effective fiber-optically isolated detector [1], which can be mounted on the faces of Maxwell 40302 Rail-Gap switches, has been developed for the Atlas pulsed power generator built at Los Alamos National Labs. These 'bat-wing' or 'bow tie' detectors, as they have become known, produce a light signal in an optical fiber by driving current thru a fiber-optic transmitter (HFBR1464T) as shown in Fig. 2. The voltage to drive this current is produced by the collapsing electric field as the switch changes to a low resistive state. The collapsing E-field capacitivly couples voltage to a pair electrodes etched on a printed circuit board along with the rest of the circuit. This hardware design can be easily reproduced and is readily mounted to the face of a Rail-Gap switch even under oil.

The outputs from the 'bat-wing' detectors as used on the Atlas pulsed power system are fed into high-resolution (0.25 ns) time-interval meters. Timing data from this system is used to monitor performance of the 192 Atlas rail-gaps.

A b-dot probe that sensed fault current in the transmission line and initiated a trigger pulse provided the signal for the original FRX-L Main Bank Pre-fire Protection system. This circuit had to be very sensitive however and was subject to cross talk from other systems. The solution lay with the bat-wing E-field detector, which produces signals of different amplitudes relative to its proximity to a switch. Thus a threshold circuit can be used discriminate between the normal operation of other banks and a Main Bank pre-fire.

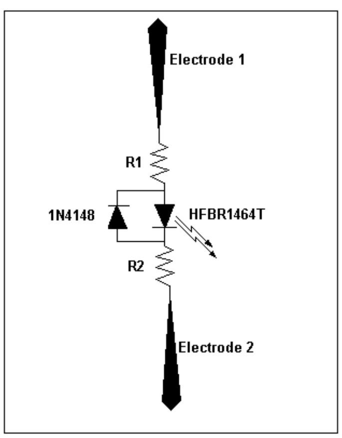

Figure 2. Detector Schematic

III. PRE-FIRE DISCRIMINATION CIRCUIT

The pre-fire discrimination and trigger circuit is located in a rack mount cabinet that also houses the Maxwell 4168 trigger generators for the P.I, Main and Crowbar switches. This circuit OR's the switch-mounted detector signals with the system trigger from the screen room. The signals from the detectors and from the screen room are fiber optic. Signals from either the screen room or from a Main bank pre-fire will exceed the threshold level of the discriminator, sending a trigger to the Maxwell master trigger unit, however, signals picked up by the detectors that are caused by other systems are not large enough to exceed the threshold and therefore do not initiate a trigger.

Because the P.I. Bank switch is identical to the Main Bank switches, it was used to simulate a Main Bank pre-fire during testing, thereby eliminating the need to actually pre-fire the Main Bank. Placing a bat-wing on the single P.I. Bank rail-gap switch and allowing the switch to self-break determined the upper threshold level for the discriminator circuit. The detectors were then mounted on the Main Bank switches and the P.I Bank was fired. The op-amp gains were tailored so the pulses picked up from the firing of the P.I Bank did not exceed the discriminator threshold level.

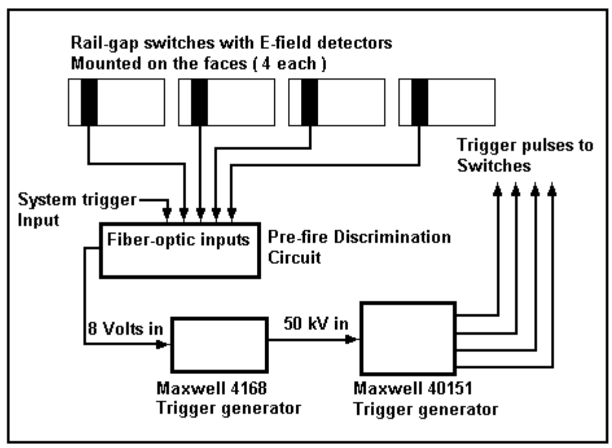

Figure 3. Pre-fire Detection System Block Diagram

Final checkout of the entire pre-fire detection circuit is difficult since it is always risky and highly undesirable to pre-fire the Main Bank switches under any circumstances. Placing each of the bat-wings, one at a time, on the P.I Bank switch and observing that the main bank trigger is fired during a P.I. Bank self-breakdown can provide an approximation of a Main Bank switch pre-fire, however this procedure does have some limitations, since the P.I Bank and the Main Bank are in many ways different

IV.PERFORMANCE

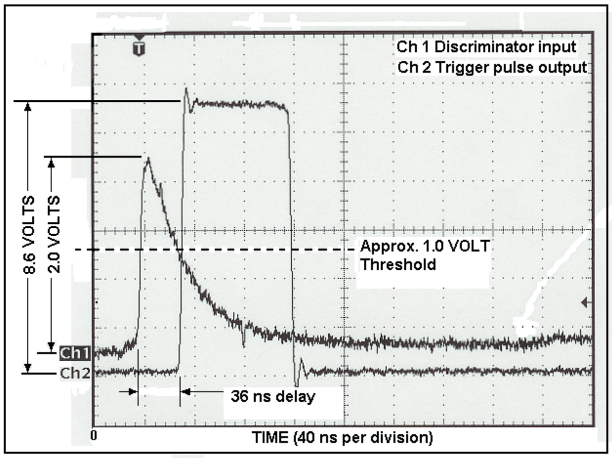

Figure 4. Discriminator and output pulses

As discussed in the previous section, one of the most important performance criteria for a pre-fire protection circuit is the ability to discriminate between an actual pre-fire and signals caused by other sources such as trigger noise from another bank. A second important criterion, though, would be the requirement of a short time delay between when the pre-fire is detected and when the rail-gap switches are then triggered.

In this system the selection of R1 and R2 on the detector circuit board (as shown in Fig. 2) and the selection of Op-amp gain in the discriminator circuit, allows for a wide range of discriminator settings which can be tailored to fit most Pulsed Power environments.

The detector response time is 10 nanoseconds [1] if one assumes the switch closure time is similar for both a self-breakdown and a triggered closure. This, added to the transit time thru the discriminator circuit, which is approximately 40 nanoseconds as shown in Fig. 4, means a pre-fire signal is present at the trigger inputs of the trigger generators in about 50 nanoseconds.

The insertion delay for the Maxwell 40168 Trigger Generator is 200 nanoseconds, and for the 40151 Multiple Trigger Generator it is 40 nanoseconds. Combining all of these delays yields a total delay time of about 1.1 microseconds between the sensing of a pre-fire break down and the arrival of a high voltage trigger pulse at the grail-gap trigger electrodes. Since the quarter cycle rise time of the FRC-L Main Bank is 3.0 microseconds the voltage across the switches will only be down by about one third of the bank charge voltage (usually 70 kV) at this time, allowing the remaining switches to close.

Since the installation of this pre-fire detection system, the Main Bank has experienced one pre-fire due to a loss of gap pressure, but because the pre-fire system was in place, the rail-gap switches were undamaged.

V. SUMMARY

A pre-fire detection system has being developed by the Los Alamos MTF team to protect the Main Bank closing switches in the FRX-L pulsed power system. This system is fast enough to protect the rail-gaps in the event of a pre-fire fault. It is simple and inexpensive to build and install, and in the future it could be used to provide not only pre-fire protection but also information on switch performance that would aid in trouble-shooting and maintenance of high-energy pulse power systems using rail-gap switches.

VI. REFERENCES

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[2] C. Grabowski, et al., “Development of a High-Current Low Inductance Crowbar Switch for FRX-L”, in IEEE TRANSACTIONS ON PLASMA SCIENCE, Vol. # 30 No.5, October 2002